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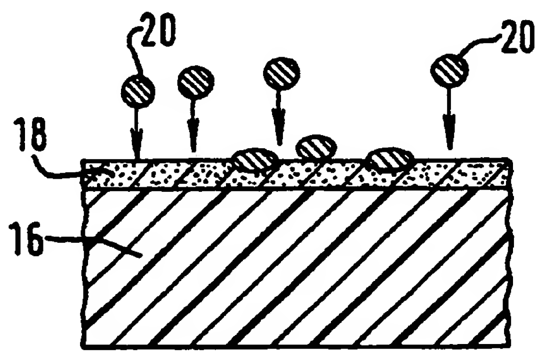
(54) Title: INSULATED ELECTRICAL CONDUCTOR AND CONTACTING METHOD

(57) Abstract

An insulated electrical conductor for high voltage (10 to 800kV) windings comprises central conductive means and an outer semiconductive layer (18), a portion of which is coated with a coating comprising metal particles (20) for grounding purposes. The particles are preferably accelerated towards the outer layer (18) in a gas stream. A grounding wire may be connected to the coated outer layer by means of a resilient metallic spring member.



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INSULATED ELECTRICAL CONDUCTOR AND CONTACTING METHOD

The present invention relates to an insulated electrical conductor. More specifically, the invention relates to an insulated conductor, for use in high-voltage windings, having an outer layer of (at least semi-) conductive material which is contacted for grounding purposes. The conductor is intended to be used in large motors, generators and transformers at voltages in excess of 10 kV, in particular in excess of 36 kV, and preferably more than 72.5 kV up to very high transmission voltages, such as 400 kV to 800 kV or higher. In addition, the invention relates to a method of establishing electrical contact with (semiconductive) polymeric material.

A particular conductor which can be used in the invention is shown in cross section in Figure 1. The conductor 10 comprises strands 12, for example of copper, the majority of which are insulated, surrounded by a first conductive layer 14. An insulating layer 16, for example of cross-linked polyethylene (XLPE) surrounds the first conductive layer 14 and is in turn surrounded by a second conductive layer 18.

Whilst the layers 14, 18 are described as "conductive" they are in practice formed from a base polymer mixed with carbon black or metallic particles and have a volume resistivity of between 1 and 10^5 $\Omega\cdot$cm, preferably between 10 and 500 $\Omega\cdot$cm. Suitable base polymers for the layers 14, 18 (and for the insulating layer 16) include ethylene vinyl acetate copolymer/nitrile rubber, butyl grafted polythene, ethylene butyl acrylate copolymer, ethylene ethyl acrylate copolymer, ethylene propene rubber, polyethylenes of low density, poly butylene, poly methyl pentene and ethylene acrylate copolymer.

The first conductive layer 14 is rigidly connected to the insulating layer 16 over the entire interface therebetween. Similarly, the second conductive layer 18 is rigidly connected to the insulating layer 16 over the entire interface therebetween. The layers 14 - 16 form a solid insulation system and are conveniently extruded together around the strands 12.

Whilst the conductivity of the first conductive layer 14 is lower than that of the electrically conductive strands 12, it is still sufficient to equalise the potential over its surface. Accordingly, the electric field is distributed uniformly around the circumference of the insulating layer 16 and the risk of localised field enhancement and partial discharge is minimized.

The potential at the second conductive layer 18, which should be zero or ground, is equalized at this value by the conductivity of the layer. At the same time, the conductive layer 18 has sufficient resistivity to enclose the electric field. In view of this resistivity, it is desirable to connect the conductive polymeric layer to ground at intervals therealong.

A problem experienced in making electrical contact with polymeric layers is that they expand in use, due to their high thermal expansion coefficient, and also creep under mechanical loading.

Paints or glues containing silver particles are sometimes used for contacting microelectronic devices which carry extremely low signal currents.

According to the present invention there is provided an electrical conductor for high voltage windings, comprising central conductive means and an outer semiconductive layer, characterised in that a portion of the surface of the

conductor is coated with a coating comprising metal particles.

In a preferred embodiment, the central conductive means comprises one or more strands of wire and is surrounded in turn by an inner layer of lower conductivity than the wire, then by an electrically insulating layer and then by the outer layer, which preferably has a higher conductivity than the insulating layer.

The coating may be a paint or glue, but more preferably, the coating comprises an impact-bonded layer of metal particles. These particles preferably comprise silver particles.

The coating may directly coat the outer polymeric layer, but advantageously a metallic foil, such as silver foil, is interposed between the coating and the polymeric layer. The coating (and foil if present) may be applied to a plurality of portions of the polymeric layer at intervals along the conductor.

In a preferred embodiment, at least one grounding wire is connected to the coating.

According to the invention there is also provided a method of establishing electrical contact with a semiconductive polymeric material, comprising applying a coating comprising metal particles, preferably comprising silver particles.

The coating may be painted on, but more preferably the coating is formed by accelerating the metal particles towards the polymeric material, for example in a gas stream.

In one embodiment, the coating is applied directly to the surface of the polymeric material. In an alternative embodiment, the method comprises the steps of bonding a

metal foil to the surface of the polymeric material and applying the coating to the external surface of the metal foil. The metal foil could be bonded to the semiconductive polymeric material by ultrasonic welding.

If the polymeric material is a semiconductive outer layer of an electrical conductor, the method may additionally include connecting at least one grounding wire to the coating. The at least one grounding wire may be connected by soldering or by means of a spring-type contacting device.

Preferably, the coating is purely metallic for electrical and thermal stability.

The method of the invention renders localized coating of the semiconductive layer relatively easy, and heating of this layer can be avoided.

Embodiments of the invention will now be described in more detail, by way of example only, with reference to the accompanying drawings, in which

Figure 1 is a transverse section through a conductor according to the invention, but not showing the coating;

Figure 2 is a fragmentary longitudinal section through the conductor of Figure 1, showing the coating being applied according to one embodiment, and

Figure 3 is a section similar to Figure 2, showing the coating being applied according to an alternative embodiment.

Figure 2 shows how small silver particles 20 are accelerated towards the surface of the conductive polymeric outer layer 18. The particles 20 impact the surface of the layer 18, penetrating that layer and contacting the

particles of carbon therein. Subsequent particles 20 build up a coating of silver.

Figure 3 shows an alternative embodiment in which, prior to the impact bonding, silver foil 30 is placed on the surface of the polymeric layer 18 to protect it. Silver particles 20′ are then accelerated in a gas stream, impact the silver foil 30 and form a coating thereon. In this embodiment the impact of the particles has a minimized effect on the conductive polymeric layer 18 and electrical contact therewith is improved. The silver foil 30 reduces the kinetic energy of the silver particles 20′ and prevents them from becoming embedded too deeply. Optionally the silver foil is ultrasonically welded to the polymeric layer 18.

Once the silver particle coating has been applied to the conductor 10, grounding wires can be connected thereto. A resilient metallic spring member (not shown) may be placed around the coated portion of the conductor for this purpose, and a grounding wire may be soldered to the spring member. The spring member may comprise a helical spring in an endless loop arranged around the conductor, or an elongate helical spring urged against several turns of the wound conductor. The spring member is preferably of a clad metal, such as a copper alloy clad with silver, gold or platinum.

The method of the invention is compatible with the extrusion process by which the conductor (which may be a superconductor) is produced. The outer conductive polymeric material is not damaged, particularly since mechanical stresses are minimized and chemical reactions avoided.

The electrical insulation of an electrical conductor according to the invention is intended to be able to handle very high voltages, e.g. up to 800 kV or higher, and the consequent electric and thermal loads which may arise at these voltages. By way of example, electrical conductors

according to the invention may comprise windings of power transformers having rated powers from a few hundred kVA up to more than 1000 MVA and with rated voltages from 3 - 4 kV up to very high transmission voltages of from 400 - 800 kV or more. At high operating voltages, partial discharges, or PD, constitute a serious problem for known insulation systems. If cavities or pores are present in the insulation, internal corona discharge may arise whereby the insulating material is gradually degraded eventually leading to breakdown of the insulation. The electric load on the electrical insulation in use of an electrical conductor according to the present invention is reduced by ensuring that the inner layer of (semi)conductive material of the insulation system is at substantially the same electric potential as conductors of the central electrically conductive means which it surrounds and the (semi)conductive outer layer is at a controlled, e.g. earth, potential. Thus the electric field in the electrically insulating layer between these inner and outer layers is distributed substantially uniformly over the thickness of the intermediate layer. By having materials with similar thermal properties and with few defects in these layers of the insulation system, the possibility of PD is reduced at given operating voltages. The electrical conductor can thus be designed to withstand very high operating voltages, typically up to 800 kV or higher.

CLAIMS

1. An electrical conductor for high voltage windings, comprising central conductive means and an outer semiconductive layer, characterised in that a portion of the surface of the conductor is coated with a coating comprising metal particles.

2. An electrical conductor according to claim 1, wherein the central conductive means comprises one or more strands of wire and is surrounded in turn by an inner layer of lower conductivity than the wire, then by an electrically insulating layer and then by the outer semiconductive layer.

3. An electrical conductor according to claim 1 or 2, wherein the outer semiconductive layer comprises one or more polymers and carbon black, and has a volume resistivity of between 1 and 10^5 $\Omega\cdot$cm.

4. A conductor according to claim 3, wherein the resistivity of the outer semiconductive polymeric layer is between 10 and 500 $\Omega\cdot$cm.

5. A conductor according to claim 1, 2, 3 or 4, wherein the coating comprises a paint or a glue.

6. A conductor according to claim 1, 2, 3 or 4, wherein the coating comprises an impact-bonded layer.

7. A conductor according to any one of the preceding claims, wherein the metal particles comprise silver particles.

8. A conductor according to any one of the preceding claims, wherein a metallic foil is interposed between the coating and the outer semiconductive layer.

9. A conductor according to claim 8, wherein the metallic foil comprises silver foil.

10. A conductor according to any one of claims 1 to 7, wherein the coating directly coats the outer semiconductive layer.

11. A conductor according to any one of the preceding claims, wherein the coating coats a plurality of portions of the conductor at intervals therealong.

12. A conductor according to any one of the preceding claims, wherein at least one grounding wire is connected to the coating.

13. A conductor according to claim 12, wherein the grounding wire is connected by means of a resilient metallic spring member.

14. A conductor according to any one of the preceding claims, characterised in that the electrically conductive means and outer semiconductive layer are designed for high voltage, suitably in excess of 10 kV, in particular in excess of 36 kV, and preferably more than 72.5 kV up to very high transmission voltages, such as 400 kV to 800 kV or higher.

15. A conductor according to any one of the preceding claims, characterised in that the electrically conductive means and outer semiconductive layer are designed for a power range in excess of 0.5 MVA, preferably in excess of 30 MVA and up to 1000 MVA.

16. A method of establishing electrical contact with a semiconductive polymeric material, comprising applying a coating comprising metal particles.

17. A method according to claim 16, wherein the coating comprises silver particles.

18. A method according to claim 16 or 17, comprising painting the coating.

19. A method according to claim 16 or 17, comprising accelerating the metal particles towards the semiconductive polymeric material.

20. A method according to claim 19, wherein the particles are accelerated in a gas stream.

21. A method according to any one of claims 16 to 20, wherein the coating is applied directly on to the surface of the semiconductive polymeric material.

22. A method according to any one of claims 16 to 20, comprising the steps of applying a metal foil to the surface of the semiconductive polymeric material and applying the coating to the external surface of the metal foil.

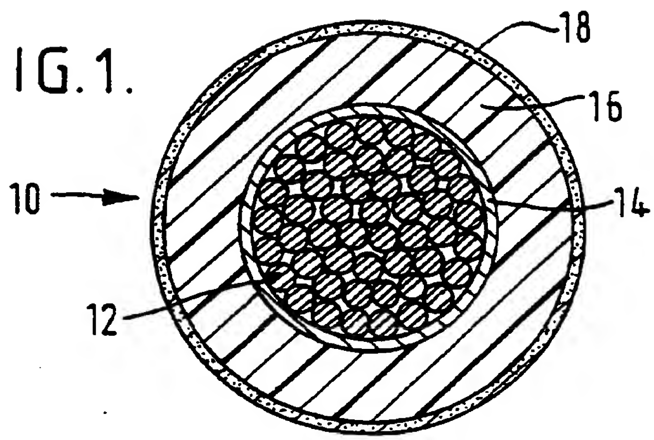
23. A method according to claim 22, wherein the foil is bonded to the semiconductive polymeric material by ultrasonic welding.

24. A method according to claim 22 or 23, wherein the foil comprises silver foil.

25. A method according to any one of claims 16 to 24, wherein the semiconductive polymeric material is a semiconductive outer layer of an electrical conductor.

26. A method according to claim 25, including an additional step of connecting at least one grounding wire to the coating.

FIG.1.



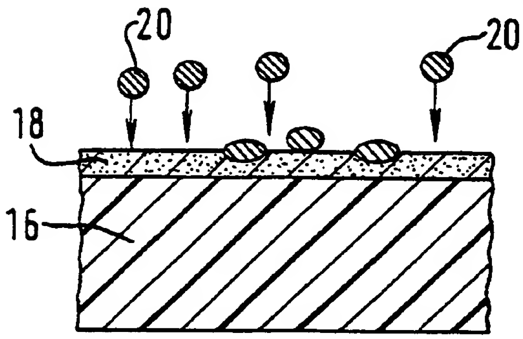
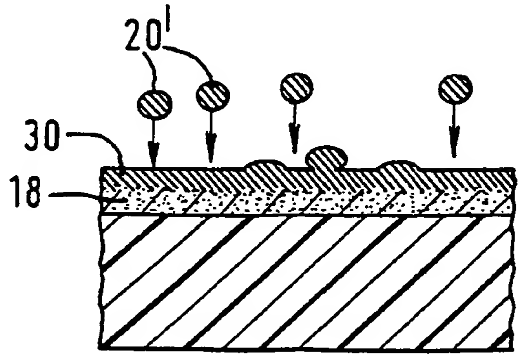


FIG. 2.

FIG.3.



INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP 98/07734

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H02K3/40 H01F5/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H02K H01F H01B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 3 666 876 A (FORSTER) 30 May 1972 see column 6, line 39 - column 8, line 42; figures 3A,3B	1,7,10, 12,16
A	DE 40 22 476 A (THYSSEN) 16 January 1992 see column 3, line 11 - column 4, line 53; figures 1-3	1-3,8,10
A	US 4 312 793 A (CHARNESKI ET AL.) 26 January 1982 see claims 1-13; figure 1	1,6,16

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 3666876 A	30-05-1972	NONE	
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